CHAPTER 11
GOVERNMENT TESTING

This chapter describes the objectives of Government testing. Also, the typical scope of contractor preparation and delivery of the test articles to Government test sites are described,.

11.0 LIST OF SYMBOLS

cm		centimeters
D	=	actuator displacement, units
F	=	force applied to the controller by
	=	pilot, units
m	=	
n/rev	=	cycles per revolution
N_1	=	compressor speed, rev/min.
N_2	=	power turbine speed, rev/min.
N_g	=	gas producer speed, rev/min.
N_p	=	power turbine speed, rev/min.
P_c	=	probability of classification
$P_{C/D}$	=	probability of class-ification given detection
P_D	=	probability of detection
P_E	=	probability of engage ment
$p_{E/C}$	=	probability of engagement given classification
$p_{H/E}$	=	probability of hit given engagement
s	=	seconds
t	=	time the force is applied
V_{BG}	=	best glide airspeed, K_t
Vcruise	=	velocity for cruise, K_t
Vcruise climb	=	cruise climb airspeed, K_t
Vmax	=	maximum level flight airspeed, K_t
VmaxROC	=	velocity for maximum rate of climb, K_t
VminROC	=	velocity for minimum rate of descent, K_t
V_{NE}	=	never exceed velocity, K_t
g	=	acceleration of gravity
K_t	=	calibrated airspeed
W/m2	=	watts per meter squared
$\iota\rho\theta$	=	phase delay measured in seconds
$\varpi_{\beta\varpi\phi}$	=	bandwidth measured in radians per second

11-1 INTRODUCTION

Government test and evaluation (T&E) programs should be structured to provide essential information to decision-makers, assess attainment of technical performance parameters, and determine whether systems are operationally effective, suitable, and survivable for intended use. See Department of Defense Regulation, DoD 5000.1, *Defense Acquisition* (Ref. 1). Government developmental testing is conducted to assess specification compliance with critical parameters, identify technological risks, and determine readiness to proceed to the initial operational test (IOT). Appropriate Government operational testing (OT) should be conducted to provide data for operational assessments, with the IOT being conducted to determine operational effectiveness and suitability of the system under realistic conditions. Army Regulation (AR) 73-1, *Test and Evaluation Policy* (Ref. 1) specifies in detail the concepts, objectives, policies, and techniques of Government development and operational testing. In addition to defining the need for development and operational testing, the statement of work should address all requirements for test articles, such as test article preparation, test article configuration, instrumentation, data acquisition and reduction requirements, technical support, maintenance and logistical support, schedule of performance, and contractor support. It is envisioned under current acquisition reforms that OT and Developmental (DT) will be integrated when ever feasible.

11-2 TEST AND EVALUATION MASTER PLAN (TEMP)

The TEMP documents the overall structure and objectives of the T&E program. It provides the framework used to generate detailed T&E plans and documents schedule and resource implications associated with the T&E program. The DoDR 5000.2-R, *Mandatory Procedures for Major Acquisition Programs (MDAPs) and Major Automated Information System (MAIS) Acquisition Programs,* (Ref. 4) addresses the scope and format of the TEMP. The TEMP relates program schedules, test management strategy and structure, and the required resources to address:

1. Critical operational issues and criteria (COIC)
2. Critical technical parameters
3. Minimum acceptable operational performance requirements
4. Evaluation criteria
5. Milestone decision points.

Continuous evaluation (CE) is an overall process which provides a continuous flow of all available T&E information. It should be used to ensure responsible, timely, and effective assessments of the status of a system. CE includes planning, testing, and data collection and analysis, and furnishes evaluations, conclusions, and reports to the decision maker and all members of the acquisition team (AT). Life-cycle CE is discussed in detail in AR 73-1 (Ref. 1).

A Test Integration Working Group (TIWG) is chartered by the program sponsor (the term program sponsor applies to the program manager, project manager, product manager, or equivalent manager) to prepare the TEMP. The TIWG and the types of tests and evaluations applicable to US Army air vehicles are discussed in subparagraphs that follow.

11-2.1 TEST INTEGRATION WORKING GROUP (TIWG)

A TIWG is established to ensure that the various tests are integrated properly. The primary purposes of the TIWG are to optimize the use of appropriate T&E expertise, instrumentation, facilities, simulations, and models to achieve test integration, thereby reducing costs. The TIWG:

1. Integrates test requirements, accelerates the TEMP coordination process by producing a TIWG coordinated TEMP, resolves cost and scheduling problems, and determines test data confirmation.

2. Provides a forum through which T&E coordination among all members of the acquisition team is accomplished.

3. Supports CE by accomplishing early, more detailed, and continuing T&E documentation, planning, integration, and sharing of data. The TEMP is coordinated by the principal TIWG members and staffed by the program sponsor for approval at the decision making level. Also, the TIWG interfaces with other groups that could be chartered to support the program sponsor, such as manprint joint working groups (MJWG), and computer resources working group. The MJWG interfaces the domains of manpower, personnel, training, human factors, system safety, health hazards, and soldier survivability discussed further in Chapter 10. Any modifications affecting the T&E must be coordinated and approved as changes. The TIWG members monitor the T&E specified in the TEMP, participate in the TIWG process on a continuing basis by attending periodic TIWG meetings, and assist in development of the TEMP. The principal TIWG members (and their main responsibilities in addition to assistance with preparation of the TEMP) consist of:

1. Program Sponsor. TIWG Chairman and responsible for TEMP development to include establishing the schedule for development of the TEMP.

2. Combat Developer. Responsible for formulating doctrine, concepts, requirements, and organizations.

3. Developmental Tester. Responsible for the technical detailed test plan and execution of technical testing.

4. Independent Developmental Evaluator. Responsible for technical test integration as a member of the TIWG and development of the independent evaluation plan.

5. Operational Tester. Responsible for the operational detailed test plan and execution of operational testing.

6. Independent Operational Evaluator. Responsible for operational test integration as a member of the TIWG and development of the test and evaluation plan.

7. Logistician. Responsible for independent evaluation of system reliability, availability, and maintainability (RAM).

8. Trainer. Responsible for the training of test and unit personnel.

9. Threat Systems Officer. Responsible for providing the operational threat environment.

10. Survivability/Lethality Analysis Directorate (SLAD) of the US Army Research Laboratory (ARL).

11. Federal Aviation Administration (FAA) Representative if FAA certification will be required.

11-2.2 TECHNOLOGY FLIGHT EVALUATIONS (TFE)

The TFE is a flight evaluation and research effort conducted by the test agency on foreign (non-exploitation testing) and domestic air vehicle to include systems and subsystems. The objective of the TFE is to determine the state of the technology of the air vehicle, systems, and subsystems. A typical TFE test article could be a foreign attack rotorcraft, and the scope of typical TFE testing could include performance, handling qualities, armament, air vehicle survivability equipment (ASE), and mission equipment package (MEP) testing. Test results generated by the TFE are applicable to determining how Army technology compares to foreign technology and evaluation of potential improvements.

11-2.3 FLIGHT SIMULATION EVALUATIONS (FSE)

The FSE is a simulator evaluation conducted by the test agency on motion-based simulators that simulate representative air vehicle stability and control characteristics. The objective of the FSE is to determine if the characteristics of the simulator are representative of the actual flight characteristics of the air vehicle. The scope of FSE testing should include handling qualities and performance tests to determine how well the simulation replicates the air vehicle and the impact of any fidelity limitations. These evaluations may also be conducted on simulators which represent generic air vehicle stability and control characteristics, or are used to evaluate new concepts. A typical simulator is the UH-60 Synthetic Flight Training System (Device 2B38), designed and built by the Link Company, [*] Flight Simulation Division, Binghamton, NY. The simulator is a six degree-of-freedom (DOF) motion and visual system which simulates a natural rotorcraft environment. An FSE was conducted on the simulator by experimental test pilots and included performance and handling qualities' tests. Test results are typically used to upgrade software to allow greater fidelity of rotorcraft and simulator.

[*]The naming of this company in no way implies an endorsement by the US Government.

11-2.4 CONTRACTOR DEVELOPMENT, SPECIFICATION COMPLIANCE, AND QUALIFICATION TESTS

Typically, the contractor accomplishes most development, specification compliance and qualification testing, using the contractor's facilities. Some testing may have to be accomplished at military unique facilities. The PA normally requires submittal and approval of the contractor's test plans and reports as specified in the contract. The development portion of the tests is used to prove out the individual parts, components, subsystems, and total air vehicle system, including separately developed allied equipment and mission equipment package (MEP). Qualification tests are performed to prove that the item under test (component, subsystem, etc.) will perform to specifications for its specified life.

For onboard allied equipment being separately developed, and for which working samples are unavailable, a correctly positioned and secured load of proper weight and volume representative of this equipment should be abroad the air vehicle. Also for air vehicles; the objectives of the contractor's testing should include demonstration of the flight envelope; acceptable limitations, restrictions, and emergency procedures. A contractor flight release is usually required, see Appendix C. Governmental witnessing or monitoring of the tests is conducted at the discretion of the Government. Contractor testing and the purpose of the resulting data should be identified in the TEMP, and included as part of the integrated test program. The TEMP should identify tests that will be conducted by the contractor and witnessed by the Government such that the data can be used to satisfy the Government test requirements.

11-2.5 ARMY EXPERIMENTAL FLIGHT TESTS

Experimental flight testing is that flight testing that has not been previously performed on an air vehicle by the contractor or responsible Government agency. Experimental flight testing includes testing systems, subsystems, components, allied equipment, and MEP. The US Army Aviation and Troop Command ATCOM) should determine the requirements for experimental flight testing on air vehicles that are to be flown by Army experimental test pilots. Army experimental flight testing should be conducted when it is not feasible for a contractor to conduct the test. This may occur when no contract exists and the Government is developing in-house hardware or software requiring flight testing, when a vendor developing a subsystem has no flight test capability, or when the test air vehicle is with an operational unit. Prior to conducting an experimental flight test, the ATCOM agency responsible for issuance of an airworthiness release (AWR) should prepare and approve a flight release for the air vehicle being tested. The AWR should state that the flight testing to be conducted is experimental and approved by ATCOM. Experimental flight testing should be preceded by engineering analyses, ground tests, and simulations, as required. Analyses should be comparable in technical scope to that which would be performed by industry prior to release of the air vehicle for flight testing. Normally, experimental flights should be limited to 80% of the design envelope load factor or to the maneuver conditions for which required control inputs and air vehicle responses can be accurately predicted.

11-2.6 PRELIMINARY AIRWORTHINESS EVALUATION (PAE)

The TEMP should document the requirements for a PAE of an air vehicle system. The PAE could be accomplished during the demonstration and evaluation phase of test or accomplished early in the Engineering and Manufacturing Development Phase. The TEMP should identify critical operational issues and critical technical parameters and should outline the approach that will be used to capture required data. PAE is usually conducted at the contractor's facility on a prototype air vehicle during development, or of a developed air vehicle undergoing major modifications. The overall purpose of the PAE is to conduct early evaluations on the air vehicle system to determine the status of development, specification compliance, and early identification and correction of deficiencies. The PAE can be used to identify design problems, ascertain that solutions are in hand, to support decisions, and provide recommendations as to readiness of the system. A detailed description of the PAE is contained in paragraph 11-3.

11-2.7 ENDURANCE TEST

Endurance tests are conducted at the contractor's facility and/or Government test sites on a prototype or production air vehicle. The test normally is conducted on an accelerated basis encompassing a minimum number of flight hours specified by the procuring activity. The purpose of the test is to determine the endurance and reliability of the basic design and to determine the adequacy of design changes to correct deficiencies revealed during other tests. If the contractor conducts the tests, monitoring or participation by the Government may be required. The endurance test may also be conducted by the Government as lead-the-fleet (LTF) testing on a limited number of air vehicles after fielding of the system. During LTF testing, the LTF air vehicle should be flown using typical mission profiles under an accelerated flying hour program to build up airframe time faster than typical fleet usage. This allows early identification and correction of deficiencies. Sample data collection (SDC) techniques typically used by Army or contractor personnel for RAM requirements are covered in Chapter 10.

11-2.8 AIRWORTHINESS AND FLIGHT CHARACTERISTICS (A&FC) TEST

The TEMP should document the requirements for an A&FC test of an air vehicle system. The PAE typically is accomplished during the Engineering and Manufacturing Development Phase. The role of this test is for Army test pilots to make a final evaluation and document the handling qualities and performance of the air vehicle. The A&FC may be conducted on prototype, preproduction, or production air vehicle, usually at Government facilities. The purposes of the A&FC test are similar to engineering tests. The objectives of the A&FC tests are to obtain the final determination of:

1. Specification compliance in appropriate areas
2. Detailed information on performance, handling qualities, structures, and integrated systems characteristics
3. Feasibility of operational techniques for inclusion in technical manuals and other publications. A more detailed description of the A&FC is contained in paragraph 11-4.

11-2.9 CLIMATIC TESTS

Controlled climatic tests are conducted on development prototype or production air vehicle by the Government or the contractor (under Government supervision) at a Government facility such as the US Air Force (USAF) Climatic Laboratory located at Eglin Air Force Base (AFB), FL. The climatic tests are conducted at extreme environmentally controlled conditions (primarily temperature and humidity), often beyond the normal operating limits. The role of climatic qualification tests is to demonstrate to the Army the adequacy of the total air vehicle system, subsystems, and components to function satisfactorily throughout the full range of the specified operational environment. The climatic test might also establish the limits of safe operation at extreme temperatures. The climatic test is a prerequisite for follow-on developmental testing at the US Army Test and Evaluation Command (TECOM) test centers to include Yuma Proving Ground (desert natural environment), Cold Region Test Center (cold natural environment), and the Tropic Test Center (tropic natural environment).

11-2.10 SURVIVABILITY TESTS

Survivability testing is conducted to determine the capability of a system to avoid or withstand man-made hostile environments without suffering an abortive impairment of its ability to accomplish its designated mission. In general, these threats include ballistics; electronic warfare, nuclear weapons effects; nuclear, biological, and chemical (NBC) contamination; directed energy as well as advanced threats, such as high-power microwave or radio frequency (RF) weapons. Specific weapons should be identified in the SOW. Although the exact procedures and tests to assess the survivability of any system may vary, the general approach is similar. It should address the relationship among avoidance, evasion, and vulnerability capabilities of the system, DA PAM 73-series (Ref. 2). Survivability testing is addressed in the TEMP with the major emphasis on live-fire testing. A more detailed description of survivability tests is contained in paragraph 11-6.

11-2.11 OPERATIONAL TESTS (OT)

OT is a generic term encompassing operational test and experimentation in realistic, operational environments with users who represent those expected to operate and maintain the system when it is fielded or deployed. All OTs that are conducted and the developmental tests that are used as data sources for operational evaluation or assessment should be identified in the TEMP. A more detailed description of OT is contained in paragraph 11-9.

11-2.12 FOLLOW-ON EVALUATIONS (FOE)

The FOE is conducted during follow-on tests (FOT). The FOT is the OT that may be necessary during or after the production phase to refine the estimates made during the IOT, provide data to evaluate changes, verify that deficiencies in materiel, training, or concepts have been corrected, and provide data to ensure that the system continues to meet operational needs and that it retains its effectiveness in a new environment or against a new threat. The TEMP should include planning for FOE.

11-2.13 SOFTWARE TEST AND EVALUATION

Software test and evaluation should be managed and engineered using best processes and practices that are known to reduce cost, schedule, and technical risks

Except when developed by itself, Government participation in software T&E is primarily one of management oversight and procedural test witnessing. The Government's role is to validate that the software being tested meets the established software performance requirements and contributes to airworthiness of the air vehicle. The Government also has a responsibility to provide an independent verification and validation (IV&V) capability for an unbiased assessment of the software and its qualification testing. Planning for software test activities should be documented in the Test and Evaluation Master Plan (TEMP). See paragraph 11-11 of this document.

11-3 PRELIMINARY AIRWORTHINESS EVALUATION (PAE)

The purposes of the PAE are to:

1. Provide quantitative and qualitative engineering flight test data
2. Serve as a basis for an estimate of the degree to which the air vehicle is suitable for its intended mission
3. Assist in determining the flight envelope to be used by Army pilots for future tests and flight operations
4. Detect and allow for early correction of deficiencies
5. Provide a basis for evaluation of changes incorporated to correct deficiencies
6. Provide preliminary air vehicle performance data for operational use.

The evaluations may be conducted in various phases until the procuring activity (PA) determines that the air vehicle is acceptable for starting operational tests. The scope of the PAE depends on the type of system being evaluated, the period of time allocated for the test, and the stage of development of the system. Handling characteristics are usually evaluated;

however, it is not absolutely essential to the PAE . Also, the PAE typically does not result in quantitative performance data unless it is considered a very significant part of the evaluation and approved by the PA. The specifics of the conduct of the PAE are discussed in the following paragraphs.

11-3.1 PAE PREREQUISITE

Prior to the conduct of a PAE by the Army, the contractor should demonstrate to the PA through flight ground, fatigue, and vibration tests and analytical data that, within the allowable flight envelope, the air vehicle is aerodynamically, structurally, and functionally safe for an evaluation by Army test pilots. The contractor should configure the air vehicle as specified by the PA. The contractor should furnish such services, materials, and logistical support necessary to keep the air vehicle in satisfactory operation during the evaluation. Instructions should be provided on the operation of the equipment, operating techniques, handling qualities, emergency procedures, and other information necessary to ensure safe operation. For new air vehicle, sufficient flight instruction should be provided to satisfy test pilot training requirements to prepare them for the PAE.

Prior to start of the PAE, an AWR must be issued by ATCOM to establish the flight envelope and other operating instructions for the test. The flight release should be based upon the determination of contractor compliance with demonstration requirements and any appropriate information derived by the Army during the contractor's program. The test activity should prepare a detailed test plan based on the PAE test objectives and specific objectives defined in the test request prepared by ATCOM and submitted to the test activity.

Prior to the start of the PAE, a pre-test review should be held with representatives from the PA, the test activity, the contractor, and any other organizations concerned with the program. The purposes of the review are to:

1. Review the extent to which reevaluation requirements have been completed.

2. Review the contractor's recommended flight envelope (this may be a subset of the approved envelope in the flight release).

3. Verify the air vehicle configuration.

4. Finalize contract support requirements, coordinate data reduction requirements, define office space requirements, and define other services and supplies to be provided by the contractor.

A complete inspection of the air vehicle should be performed prior to the PAE by qualified maintenance and instrumentation technicians for the test activity. Representatives of the responsible Defense Plant Representative Office (DPRO) charged with plant cognizance at the contractor's facility should participate. The purpose of the inspection is to locate and correct any safety-of-flight discrepancies in the test air vehicle.

11-3.2 FUNCTIONAL TESTS

The objectives of the functional tests are to obtain an early qualitative evaluation of the air vehicle subsystems and equipment for the purpose of determining specification compliance and suitability for military applications. The scope should include, but not be limited to, functional tests of all subsystems and operating equipment in the test air vehicle (engine, flight controls, hydraulic, pneumatics, electrical, avionics, MEP, allied equipment, and any other subsystem required by the PA) should be conducted to determine conformance with the applicable specifications. Each subsystem should be operated in its various modes to verify adequacy of operation and compliance with specifications. Also, night lighting, vibrations, water integrity of airframe, and crew ingress and egress should be evaluated. Typically, enhancing characteristics, shortcomings, deficiencies, and specification compliance issues are identified. Nonconformance and deviation requests should be approved by the PA.

11-3.3 HANDLING QUALITIES

Handling qualities' characteristics of the air vehicle should be determined by flight test conducted in accordance with the provisions of the flight test plan approved by the PA. These tests should be conducted to establish and verify flying stability characteristics. The PA should determine all gross weight, CG, altitude, and rotor and propeller (if any) speeds used in the testing. Although there may or may not be a significant difference in handling properties (depending on hinge offset, etc.) for fully articulated, rigid, and hingeless rotor systems, handling properties testing would not be significantly different. Caution: There could be major differences in aeroelastic properties.

Common testing for rotorcraft and other aircraft involves determination of overall air vehicle static longitudinal, lateral, and directional stability and dynamic stability. Government testing for static longitudinal, lateral, and directional stability and dynamic stability are covered in subpars. 11-4.4 through 11-4.8.

MIL-STD-8785, *Flying Qualities of Piloted Airplanes* (Ref. 9) and Aeronautical Design Standard (ADS) 33, *Handling Qualities Requirements for Military Rotorcraft* (Ref. 10), each include the following common categories:

1. Operational missions
2. Loadings
3. Moments and products of inertia
4. External stores
5. Configurations
6. State of the air vehicle
7. Definitions of service and operational flight envelope (SFE and OFE, respectively).

However, methods used for the two types of air vehicles may differ greatly if an aircraft is qualified using 14CFR Part 23, *Airworthiness Standards: Normal Utility Acrobatic and Commuter Category Airplanes* (Ref. 6); 14CFR Part 29, *Airworthiness Standards: Transport Category Aircraft* (Ref. 7); or 14CFR Part 27, *Airworthiness Standards: Normal Category Rotorcraft* (Ref. 8) as a guide

For aircraft, the PA should identify stability testing conditions to be used in the testing. If 14CFR Part 23 or Part 29 are cited as the source for qualification requirements, the flight test plan should follow the stability of flight guidance in that publication. These conditions include specific airspeeds, flap positions, landing gear status, and power settings for static longitudinal stability testing.

ADS 33D-PRF (Ref. 10) establishes performance requirements for flying and ground handling qualities testing for Army rotorcraft. Use of that publication is meant to ensure that there are no limitations on flight safety or on mission capability due to deficiencies in flying qualities. The Government handling qualities testing should demonstrate or verify flying qualities for rotorcraft in accordance with ADS 33D-PRF (Ref. 10) unless specific deviations are applied.

11-3.4 NOVEL CONTROL SYSTEM EVALUATION

Conventional rotorcraft and other aircraft controls consist of one control for pitch and roll control, one control for collective pitch (or thrust) control, and one set of pedals for directional control per pilot station. These controls have traditionally had a direct mechanical linkage to flight control actuators through control tubes, pulleys, bellcranks, and mixing assemblies. However, with the advent of fly-by-wire and fly-by-light (fiber optic) flight controls, there are no direct mechanical linkages by design, and measurement of control displacements or forces may not be an accurate method of evaluating pilot control inputs. Further complicating this arrangement is the introduction of force-feel controls. With these controls in trimmed flight, a force-feel control can be displaced and released to return to neutral, with the new actuator position being a new control displacement. Generally, the displacement of the actuator will be some function of the force applied and the duration of the application.

An example of a fly-by-light and force-feel control system is the Advanced Digital Optical Control Systems (ADOCS) rotorcraft. For example, in trimmed flight, the longitudinal control could be held forward for one second, driving the actuator to a new position, released and allowed to return to neutral (no force applied), and the airspeed changed to a new value with the same longitudinal stick position. In this way, all graphical plots shown later in this chapter would have the same longitudinal stick position. However, if actuator position is recorded, those positions plotted along the vertical axes would more accurately reflect static and dynamic stability characteristics.

When evaluating novel control systems, elimination of human error in this flight testing may also become a problem. If several controls are integrated into one control stick, pilot attempts to provide input in only one axis must be closely monitored to ensure that no coupled inputs (cross controlling) are inadvertently introduced into flight testing. An example might be a sidearm controller which incorporates longitudinal, lateral, and yaw control for rotorcraft into one stick. In attempting to check inputs in the longitudinal axis, the pilot's arm and wrist may inadvertently induce lateral inputs and a yawing moment to the air vehicle.

Data collection requirements should be very similar to mechanical linkage control systems with the exception of control positions. Actuator positions or some other alternate means of measuring the commanded inputs to the control surfaces, rotors, and propellers should be determined by the test activity based on the testing requirements. In some cases, the effect of a given force application for a given duration may have to be verified. The effect of doubling a force applied to a controller for the same duration may be more than a doubling of the actuator displacement. The system could be designed to substantially increase the rate of actuator displacement for a force greater than a given threshold. In this case, flight test data should include stick force and actuator position verses time.

Instrumentation should also be similar to that required for conventional control systems, with the exceptions of requirements to measure actuator displacements and control forces.

11-3.5 TRANSITION FLIGHT

The contractor conducts the initial transitional flight tests. The Government test activity conducts tests and demonstration necessary to validate flying qualities during the transition operation. The transition flight regime is where a propulsive force in the horizontal direction is added to the vertical lift force. For a rotorcraft, this results in a change in fuselage (tail) rotor wake interaction that could have significant controllability effects. For multimode and tilt-rotor air vehicles, transfer of force responsibility is dependent on velocity, angle of attack, thrust vector angle, etc., which therefore defines a characteristic transition corridor. Examples of multimedia aircraft include compound rotorcraft that have both main rotor systems and propellers to provide thrust and main rotor systems and wings to provide lift. Typically, flight test instrumentation is needed to measure pertinent parameters, such as rotor speed, transient rotor droop, collective pitch, pedal position, torque’s, pitot and static pressures, vertical acceleration, angle of pitch, roll, and yaw, etc.

The PA should define transition flying qualities to be demonstrated. As a minimum, the testing activity's plan should identify airspeeds, altitudes, propeller/proprotor speeds, thrust vector and wing inclination normal envelopes and angles of attack, emergency envelopes for one-engine inoperative (OEI) operations, and gross weights to be tested. Characteristics to be demonstrated are the same as the qualities demonstrated in par. 9-5. The tests and demonstrations should be documented in accordance with par. 9-6. Future revisions of ADS-33 (Ref. 10) may contain specific handling qualities requirements for this transition mode of flight. Flying qualities of US military piloted vertical and short takeoff and landing (V/STOL) air vehicles are found in MIL-F-83300, *Flying Qualities of Piloted V/STOL Aircraft* (Ref. 11).

11-3.6 PERFORMANCE

The PAE should include testing to determine the air vehicle flight performance capability dependent on requirements for preliminary operational use and initial estimates of specification compliance. The evaluation should be conducted for a limited range of conditions as determined by the PA for the following flight regimes:

1. Hover (rotorcraft)
2. Takeoff
3. Accelerate-stop (aircraft)
4. Landing performance
5. Climb performance
6. Level flight
7. Stall performance (aircraft).

The AMCP 706-204, *Helicopter Performance Testing* (Ref. 12) should be used as a guide for rotorcraft flight performance testing. There is little difference in flight performance testing for a bearingless rotor system; however, there are a number of differences for V/STOL type air vehicles. For instance, there can be different nacelle angles for the same airspeed. MIL-F-83300 (Ref. 11) is useful in developing performance requirements. 14CFR Parts 23 and 29 (Refs. 6 and 7) should be used for other aircraft.

11-3.7 SUBSEQUENT PAE

Subsequent PAEs normally should be considered as necessary to accomplish:

1. Evaluation of mission-essential equipment not previously tested such as weapons, avionics, radars, forward looking infrared (FLIR) sensors, night vision systems, MEP, and ASE
2. Revaluation of characteristics which were not satisfactorily investigated or fully evaluated during earlier PAEs
3. Reevaluation of characteristics affected by changes or modifications installed since the completion of earlier PAEs.

11-3.8 **PAE** REPORTS

The test reporting requirements should be specified in the test request submitted to the test activity by the PA. The reports are used to provide test data and information for technical manuals and decision making. Distribution and special instructions for test reports are contained in the test request submitted to the test activity. Distribution of test results are generally limited to TECOM, ATCOM, and the PA. Additional distribution may be made with the approval of the PA. The following test reporting procedures apply:

1. Formal Test Reports. Formal test reports are typically required for test programs that either:

a. Have high management visibility

b. Meet test requirements delineated in a TEMP

c. Have test results which are used to assist in making a program decision.

Test results provide engineering flight test data for incorporation into the fielding documentation for the affected aircraft. Advance copies of the formal report are usually submitted to the PA within 75 days after test completion. The report should be reviewed and comments returned to the test activity in 40 days. The test activity incorporates appropriate comments, prints the report, and distributes the report within 68 days. The total processing time for the formal report is usually 183 days.

2. Abbreviated test reports. Abbreviated test reports are used instead of formal reports for those test programs not meeting the criteria of a formal test report. The time to process the abbreviated test report in the same manner as the formal report is 85 days.

3. Memorandum of Effort Reports (MER). The MER stating the test activity effort should be provided for all test requests that do not require a formal or an abbreviated report. The MER is submitted and distributed per the test request within 30 days.

11-4 AIRWORTHINESS AND FLIGHT CHARACTERISTICS (A&FC) TEST

The A&FC tests are conducted at Government facilities with prototype air vehicle, and later with production air vehicle. The objectives of the A&FC tests are to obtain final determination of:

1. Contract compliance in appropriate areas such as performance guarantees

2. Detailed information on performance, handling qualities, structures, and integrated system characteristics

3. Feasibility of operational techniques for inclusion in technical manuals and other publications.

The PA should issue a test request to the test activity at the earliest possible date. The test request should establish the specific test requirements. The specifics of the conduct of the A&FC test are discussed in the following paragraphs.

11-4.1 OBJECTIVE

The final A&FC tests are conducted as directed by the PA to obtain the final determination of:

1. Compliance with contract as appropriate

2. Compliance with military specifications

3. Detailed information on flight performance handling qualities, power plant operation, and integrated systems characteristics

4. Feasibility and development of operational techniques for technical manuals and other publications

5. Adequacy of the air vehicle systems and subsystems, including separately developed allied equipment under extreme temperature conditions

6. Adequacy of the contractor recommended flight envelope for other

ensuing Government development tests and for operational use.

11-4.2 FLIGHT PERFORMANCE

Testing should be conducted with AMCP 706-204 (Ref. 12) as a guide (rotorcraft fight) to determine the rotorcraft performance characteristics throughout the flight envelope. Specific tests should be included to ensure positive determination of compliance with all stated contract performance requirements. Such requirements may vary, depending on the model, design, and series (MDS) of the air vehicle, but the scope might include items such as maximum speed, cruise speed, range, hover ceiling (rotorcraft), service ceiling, and rate of climb. Tests should be conducted at various altitudes and for the full range of gross weights and mission configurations.

Flight performance characteristics should be determined quantitatively to provide a basis for the preparation of Chapter 7, Performance Data, of the appropriate Operator's Manual. Until it is replaced by an acceptable standard; MIL-M-63029, *Manuals, Technical: Requirements for Operator's Manuals and Checklists for Aircraft* (Ref. 13) should be used as guidance for data collection and preparation of flight performance charts; however, a waiver will be needed. The specific flight performance characteristics to be measured include:

1. Crosswind takeoff and landing limitations (aircraft)
2. Engine installation losses
3. Hover power required in and out of ground effect (rotorcraft)
4. Takeoff distance and obstacle clearance
5. Accelerate-stop distances (aircraft)
6. Minimum single engine control (aircraft)
7. Level flight power requirements
8. Climb
9. Landing stop distances (aircraft)
10. Airspeed calibration
11. Low speed critical azimuth (rotorcraft).

The performance instrumentation requirements are dependent on the type of air vehicle and performance measurements to be tested, and are based on the tests to be conducted. A test instrumentation boom system is normally installed on the test air vehicle to obtain angle of attack and sideslip as well as dynamic and static pressure pickups at a location that minimizes position errors for airspeed measurement. Additionally, a flight control rigging check is required prior to performance testing to determine correlation control positions. Engine calibration for the range of power turbine speeds N_p to be used is typically required.

Typical major instrumentation includes pitch, roll, and yaw attitudes; ship and boom airspeeds; outside air temperature; altitude; engine torque; compressor turbine speeds (N_l or N_g); power turbine speeds (N_2 or N_p); turbine gas temperature; vertical speed; elevator, pedal, rudder, aileron, and collective control positions; rotor torque; propeller speed; outside air temperature; fuel temperature; fuel; stall warning; and gear and flap positions. Other data also recorded would include run-stop locator, event, run number, flight number, weight on wheels, and instrumentation controls and indicators. When takeoff and landing tests are conducted, theodolites can be used to determine distances and heights above ground. Video or movie cameras may be required to record cockpit data.

11-4.3 VIBRATION SURVEYS

Rotorcraft vibration testing is conducted to determine its vibration characteristics. Specific tests are included to determine specification compliance. Tests are conducted at various altitudes and gross weights to include the maximum and minimum obtainable. Government vibration testing on aircraft (other than rotorcraft) is not normally conducted.

Rotorcraft vibration testing is conducted primarily to determine the magnitude of rotor induced vibration to evaluate the effect on pilot and passenger comfort, engine/airframe compatibility, structural integrity, etc. The source of low-frequency vibrations in the rotorcraft is the rotor. The forces transmitted to the rotor hub(s) are primarily at frequencies of once per revolution (1/Rev) and which are integral multiples of the number of rotor blades at the rotor hub. Consequently, a three-bladed rotor would transmit vibrations to the controls and fuselage at multiples of three cycles per rotor revolution (3/Rev, 6/Rev, and 9/Rev). Limits for the vibrations at the controls, the pilot's station, passenger stations, weapon platform interface, etc., are delineated in the specification requirements, and are usually expressed as vibration levels or intrusion indices. Measurement of these levels and intrusion indices are covered in ADS 27, *Requirements for Rotorcraft Vibration Specifications. Modeling, and Testing* (Ref. 14).

Contractor vibration testing is addressed in par. 9-7. To verify the results of this vibration testing, ADS-27 (Ref. 8) defines four flight regions to be tested for rotorcraft and tilt rotor air vehicle vibration specification compliance. If required by the PA, the testing activity must verify vibration levels and intrusion indices in these four regions.

Region I consists of all steady flight conditions with load factors between 0.75 and 1.25 g and airspeeds from hover to VCruise and to the maximum rearward and sideward flight speeds while operating within the defined power-on rotor speed limits. Region II applies to all flight conditions outside Region I with duration greater than three seconds, and Region III applies to Region II flight conditions with duration less than three seconds. Region IV applies only to tilt rotor air vehicle. However, for tilt rotor air vehicles operating in a rotorcraft mode or in transition between rotorcraft and other aircraft, Regions I, II, and III requirements may apply, as appropriate.

Crew and personnel station vibration criteria for frequencies up to 60 Hz are identified in ADS-27 (Ref. 14), as are criteria for controls, instrument panels and displays, and weapons sighting devices. Additionally, ADS-27 (Ref. 14) identifies the requirement for new air vehicles or air vehicles undergoing major modification to incorporate onboard rotor vibration diagnostics systems. Demonstration and qualification of this onboard system should be accomplished as part of the flight vibration surveys.

The parameters which must be recorded for vibration tests include oscillatory accelerations, amplitude and frequency, pressure altitude, airspeed, free air temperature, rotor speed gross weight, and mass moments of inertia.

The magnitude of the vibrations is determined primarily by rotor speed and balance, airspeed, load factor, mass distribution, center of gravity (CG), and gross weight. The mass distribution is determined by the configuration, fuel weight and location, and cargo or ballast weight and location. The effects of changing the preceding should be investigated during flight tests. Vibration levels usually increase as airspeed and load factor are increased. The revolutions per minute of the rotor (RPM) affects both the magnitude and frequency of the vibrations. Changing the mass distribution while keeping the gross weight constant can cause significant changes in the vibration levels. Vibration data usually are recorded during stabilized flight conditions throughout the flight envelope. Typically, data would be recorded in level flight at approximately ten (10) knot increments from approximately 40 knots (lowest airspeed at which reliable airspeed can be recorded) to maximum level flight airspeed (VMax), in dives to velocity-never exceed (V_{NE}), in maximum power climbs from maximum rate-of-climb VmaxRoc or cruise climb airspeed VCruise Climb and in minimum power descents from minimum rate of descent VminROD to best glide airspeeds V_{BG} Vibration levels are usually less significant in hover. However, vibration in transition from hover or to a hover often is notable.

Accelerometers are usually used to record vibration data. The accelerometers, should have the appropriate dynamic range and frequency response required to determine by the event(s) being measured. The accelerometers should be appropriately mounted and oriented, so that the measured event(s) are appropriately captured (i.e., vertical vibration measured vertically, etc.). Data can be recorded using constant band width frequency modulation (FM) or high sample rate pulse code modulation (PCM) recorders.

Data should be recorded and reduced as specified by the PA. Generally, fast Fourier transfer techniques are sufficient. The data are usually presented as amplitude versus frequency and peak rotor harmonic amplitude versus airspeed. Amplitude is generally presented in "g", frequency in Hertz, and airspeed in knots, calibrated as shown in Figure 11-1.

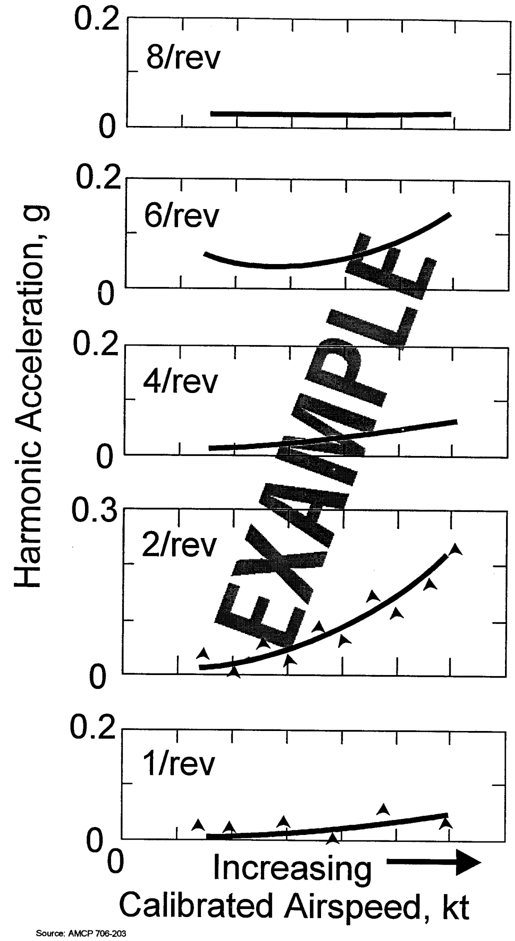


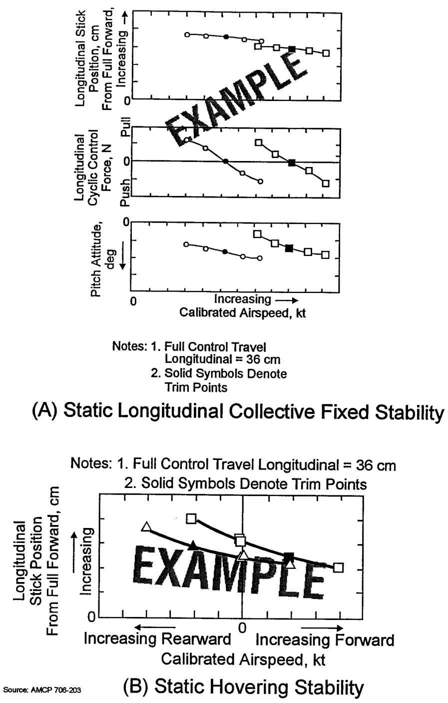
Figure 11-1 Measured Vibration

11-4.4 STATIC LONGITUDINAL STABILITY

Static longitudinal stability is the measure of the pitching moment about the air vehicle center of gravity caused by forces and moments developed on the various components of the air vehicle in flight. This pitching moment may be stabilizing or destabilizing as a function of airspeed. Static longitudinal characteristics are determined by measuring the control positions necessary to balance the pitching moment about the center of gravity. Since the position of the air vehicle CG and contribution of fuselage moments in various configurations have such a marked effect on static longitudinal stability, Government testing for static longitudinal stability may be conducted at various gross weights, CGs, and configurations defined by the PA. During this testing, collective (thrust) control is normally fixed, and longitudinal control position is varied about trim points for each combination of gross weight, CG, and configuration. Configurations should be varied from minimum fuselage drag ("clean") to high drag configurations, and contributions of the stability augmentation system (SAS) to static longitudinal stability should be considered.

Government static longitudinal stability testing should be primarily concerned with speed stability and angle of attack stability. These tests are conducted to verify that pitching moments about the air vehicle CG are either stabilizing or destabilizing forces as a function of airspeed. Other factors such as wing, tail, and fuselage contributions and power effects for propeller driven air vehicles could also have an effect. However, the test pilot is usually not concerned with the magnitude of pitching moments. The primary operational indications of static longitudinal stability are forward longitudinal, control force required to increase speed and aft longitudinal control force required to decrease speed (positive stability). The control forces required to obtain this response may also be variable, and, at increasing airspeed, a stabilizing moment produced by the rotor with increased speed may be overridden by a destabilizing fuselage pitching moment. If these characteristic are not demonstrated or verified at all test conditions, problems may arise in operational use. Fig. 11-2 illustrates positive static longitudinal stability (negative slope) in both forward flight and at a hover. Unstable longitudinal static stability would be characterized by a positive gradient on these plots which would imply a requirement for more aft control trim position for increased forward airspeed and a more forward trim control position for decreased forward speeds. This type of control response would not be intuitive to most pilots, and would result in increased workload to maintain speed control. In addition, any disturbance from trim which is not compensated for by the pilot results in a divergent response.

Characteristics to be measured may include indicated or calibrated airspeed, longitudinal control position and force,



Source: AMCP 706-203

Figure 11-2 Example Parameters Measured to Evaluate Static Longitudinal Stability

outside air temperature (OAT), rotor speed, torque of engine(s), vertical speed, pitch attitude, pressure altitude, fuel quantity, and fuel flow rate. If force controllers are used for longitudinal control, flight control actuator position may need to be recorded versus control position. Instrumentation intervals required resolution and at the specified in a Government approved test plan requirements may include oscillograph, magnetic tape, or computerized data acquisition interfaces necessary to record the previously named characteristics with the

11-4.5 DYNAMIC LONGITUDINAL STABILITY

Dynamic longitudinal stability is a term that refers to the motion of the air vehicle produced by a disturbing force to the longitudinal axis. Two modes of motion for air vehicle dynamic longitudinal stability must be evaluated for all types of air vehicle. These two modes are the short period and the long period, or phugoid, mode. Short period modes are usually associated with responses to a sharp edge pulse control displacement or to a gust, and the phugoid mode describes the response to an out-of-trim condition or to a near-step input.

An additional mode with an even shorter period might effect the dynamic longitudinal stability for aircraft when tested in a stick-free case. So short is this mode that no speed change occurs. Its' impact is that it might excite a long period mode. Since this testing usually is performed for stick-free flight for Army air vehicles, all three modes should be considered. The objective of the testing is to determine pitch, roll, and yaw attitudes and rates and fuselage angle of attack resulting from longitudinal control inputs.

The short period mode in hovering and forward flight is normally heavily damped and, therefore, nonoscillatory. SAS may be required, however, to dampen out rapid pitch responses to gusts at a hover. Both vertical and horizontal gusts must be considered for forward flight. On the other hand, long period (phugoid) responses may be shown as time histories of parameters denoting the air vehicle attitude. Such responses are shown graphically in Fig. 11-3.

All testing should be conducted beginning from trimmed flight conditions and at gross weights, CG, altitudes, and configurations as directed or approved by the PA. Additionally, iterations may be required with SAS on and off to evaluate the effects of SAS on dynamic longitudinal stability.

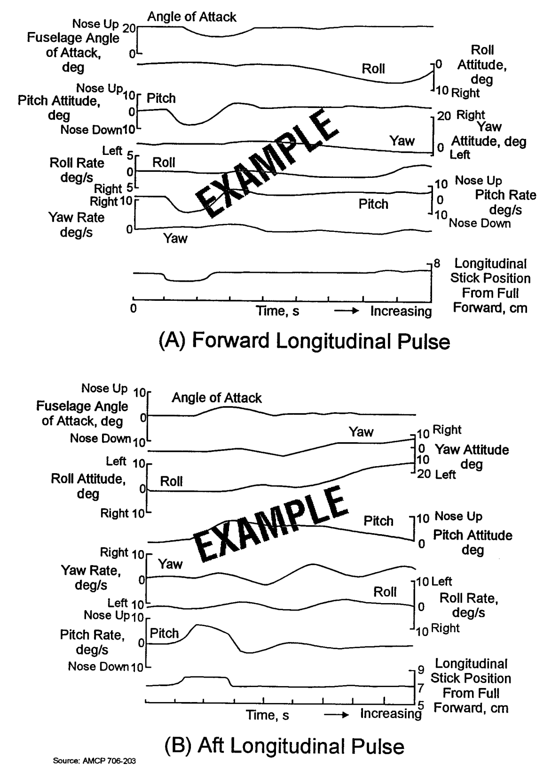


Figure 11-3 Dynamic Longitudinal Stability

For rotorcraft, the short period mode is usually evaluated at a hover starting at a stabilized airspeed of five (5) knots indicated airspeed (KIAS). Longitudinal control position is measured relative to control position in hover. This procedure is repeated in the rearward direction, and readings are taken for both forward and rearward flight. Response to gusts in forward flight is obtained by trimming the rotorcraft at a stabilized test condition. The effect of the long period response is recorded, and gust response in forward flight may be evaluated by introducing a 0.25g normal acceleration with longitudinal control pulse inputs.

Long period (phugoid) modes may be excited by displacing the longitudinal control to decrease the airspeed five (5) KIAS from trimmed airspeed and returning the control to trim. This excitation is repeated for increasing airspeed. Typical results are shown in Fig. 11-3.

Characteristics to be measured include longitudinal and collective (thrust) control positions (or actuator positions in the case of force controllers), normal accelerations in applicable directions, airspeed, pitch, roll, and yaw attitudes, rates, and accelerations, and elapsed time. Instrumentation requirements include oscillograph, magnetic tape, or computerized data acquisition interfaces necessary to record these characteristics with the required resolution and at the specified intervals. If force-feel controllers are used, actuator positions may have to be measured instead of control positions.

11-4.6 MANEUVERING STABILITY

Stability characteristics of maneuvering Army air vehicles have become particularly important with the introduction of armed rotorcraft and target designating scout rotorcraft. The stability of the platform during maneuvers contributes greatly to weapons accuracy through the target acquisition, designation, and engagement sequence. Flight tests should be conducted by the Government to evaluate the stability of the aircraft during typical high g maneuvers, such as the maneuvers of TABLE 9-1. Pull-ups, recovery from dives, and stabilized turning flight are of primary concern.

The purposes of the tests are to determine the control forces and control or actuator displacements required to develop a steady state acceleration or a pitch and/or roll rate in both level pull-ups and dives and turning flight. Positive maneuvering stability is demonstrated by the requirement for increasing force and aft displacement of the longitudinal control stick for increasing levels of normal acceleration as shown in Fig. 11-4a. Additionally, these tests should identify differences in maneuvering stability when turning left versus right, rotor speed buildup or loss, and transient torque characteristics during maneuvering flight.

For rotorcraft, Section 3.4 of ADS 33D-PRF (Ref. 10) covers mid-term pitch attitude response to a longitudinal controller input, and also covers interaxis coupling. Later paragraphs of that section also cover roll attitude response to lateral controller inputs, as well as roll-sideslip coupling. Appropriate sections of ADS 33D-PRF may be used by the Government in evaluating this characteristic. Criteria for assignment of handling qualities levels are included in that publication, and typical test requirements are shown in Fig. 11-4b.

Characteristics to be measured include indicated airspeed, pressure altitude, OAT, fuel weight, rotor speed, engine torque, longitudinal, lateral, and directional control displacement and force, collective (thrust) displacement, sideslip angle, normal acceleration at pilot's station and CG, rate of climb or descent in turns, pitch and roll rates and attitudes, and yaw rates. Instrumentation requirements may include oscillograph, magnetic tape, or computerized data acquisition interfaces necessary to record these above characteristics with the required resolution and at the specified intervals in a Government approved test plan.

11-4.7 STATIC LATERAL-DIRECTIONAL STABILITY

For static lateral-directional stability, requirements are that stability be positive for specific ranges of airspeeds for three-control airplanes. For two-control (or simplified control) airplanes, different requirements are cited, including abandonment of controls for two minutes without assumption of dangerous attitudes or speeds.

For rotorcraft, Section 3.4 of ADS 33D-PRF (Ref. 10) covers the requirements for lateral directional stability. The three main characteristics of concern are dihedral effect, directional stability, and sideforce. The objectives of the testing are to determine longitudinal, lateral, and yaw control forces and displacements and fuselage bank angles required to maintain a steady sideslip at various airspeeds. Since sideslip angles are used, reliable airspeed measurements are particularly important for all sideslip angles.

Tilt rotor and tandem rotor rotorcraft may depend on the fuselage for static directional stability, which leads to an unstable air vehicle if the fuselage is unstable. SAS may be required to provide this measure of stability.

Typical test results are shown in Fig. 11-5. Positive lateral directional stability is indicated by a requirement for increasing pedal and lateral control displacement and resulting angle of roll, for increasing sideslip. Characteristics to be measured include indicated airspeed, pressure altitude, OAT, fuel weight, rotor speed, engine torque, longitudinal, lateral, and directional control displacement and force, sideslip angle, pitch, roll, and yaw attitudes, and vertical speed. Instrumentation requirements may include oscillograph, magnetic tape, or computerized data acquisition interfaces necessary to record the

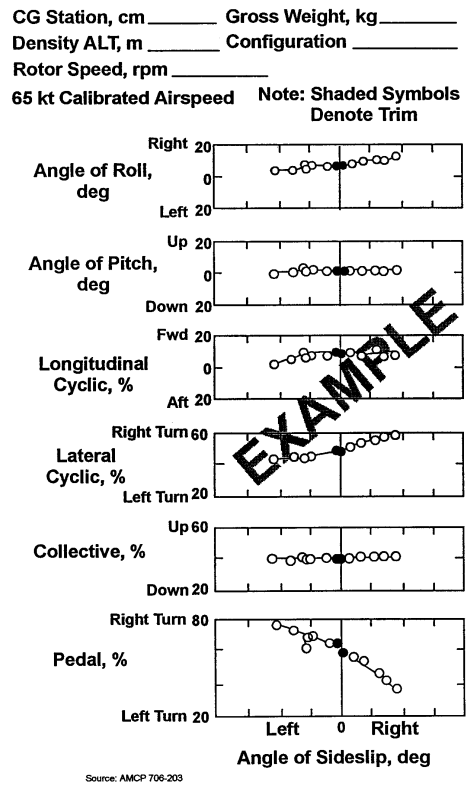


Figure 11-5 Static Lateral-Direction Stability

above characteristics with the required resolution and at the specified intervals in a Government approved test plan.

11-4.8 DYNAMIC LATERAL-DIRECTIONAL STABILITY

Dynamic lateral-directional stability testing is performed to determine air vehicle response to gust disturbances and to evaluate general flying qualities associated with lateral-directional control. Dynamic stability requirements involve testing for short period, roll, and combined lateral-directional ("Dutch Roll") oscillations.

The Dutch roll mode consists of oscillations in roll and yaw, usually at identical frequencies; however, the roll follows the yaw by a finite phase angle. Additionally, the ratio of roll oscillation to yaw oscillation is known as the roll-to-yaw ratio. As a general rule, large roll-to-yaw ratios are undesirable since pilots tend to have more trouble controlling roll than yaw.

A second factor governing the pilot's opinion of the air vehicle may be behavior following a lateral control input. Initial roll acceleration, maximum roll acceleration, final steady-state roll rate, and the time required to achieve a steady-state roll rate all influence the pilot's opinion of the air vehicle. Roll declarations required to stabilize at a bank angle are also an important concern.

After obtaining the desired bank angle through a roll acceleration/deceleration doublet, the pilot's opinion is greatly influenced by the trim holding characteristics of the air vehicle. Three things can occur when trimmed flight is disturbed in a turn. The air vehicle may return to trim, it may stabilize at a new bank angle, or the bank angle may diverge further from the trim angle (an unstable condition).

If any of these oscillations are significant, pilot compensation during tasks such as instrument meteorological condition (IMC) flight may be excessive. ADS 33D-PRF (Ref. 10) contains criteria for evaluation of these handling qualities in normal flight conditions and in terms of degraded visual cue environment.

Characteristics to be measured include indicated airspeed; pressure altitude; OAT; fuel weight; rotor speed; engine torque; collective (thrust) control position; longitudinal, lateral, and directional control displacement and force; sideslip and bank angles; normal acceleration at pilot's station and CG; rate of climb or descent in turns; pitch, roll, and yaw rates and attitudes; and time. Instrumentation requirements may include oscillograph, magnetic tape, or computerized data acquisition interfaces necessary to record these characteristics with the required resolution and at the specified intervals in a Government approved test plan. Typical graphical outputs for these flight tests are shown in Fig. 11-6.

11-4.9 TRANSITION FLIGHT

For multi-mode air vehicles which can transition from vertical take-off and landing (VTOL) or vertical/short take-off and landing (V/STOL) (primarily rotorcraft) modes to other type aircraft modes, the Government test activity may conduct tests and demonstrations necessary to verify or demonstrate flying qualities during the transition operations. Other multi-mode air vehicles may include compound rotorcraft which have both main rotor systems and propellers to provide thrust and/or main rotor systems and wings to provide lift.

In some cases, two or more possible flight modes may be possible at the same conditions. An example could be flight at 90 knots and maximum gross weight which may be possible with tilt-rotor engine nacelles/thrust vectors in the VTOL mode (zero degrees inclination to the vertical plane), in the fixed wing mode (90 degrees inclination), or any inclination between those values. Another example might be the reduction of lift requirements of the main rotor at high speeds caused by compound rotorcraft variable or fixed wing angles of attack.

The purpose and scope of A&FC flight testing in the transition flight mode is to determine operational and service flight envelopes for each mode. In some cases, airspeed may not be sufficient for continued level flight with a tilt-rotor air vehicle in the fixed wing mode, while in other cases (especially high gross weights), in-ground effect (IGE) or out-of-ground-effect (OGE) hover may not be possible. At lower airspeeds, compound rotorcraft wing surfaces may not be capable of providing sufficient lift for level flight.

The PA should define transition flying qualities to be demonstrated. As a minimum, the testing activity's plan should identify the ranges of airspeeds, altitudes, propeller/proprotor speeds, engine/vector inclination normal envelopes or wing angles of attack, emergency envelopes for one-engine inoperative (OEI) operations, and gross weights to be tested. Characteristics to be demonstrated are the same as the qualities demonstrated in paragraph 9-5, and typical test results are shown in Fig. 11-7.

The tests and demonstrations should be documented in accordance with par. 9-6. Future revisions of ADS 33D-PFR (Ref. 10) might contain specific handling qualities requirements for this mode of flight. These data should primarily be used to provide data for preparation of operator's manual performance information and emergency procedures. Instrumentation requirements could include oscillograph, magnetic tape, or computerized data acquisition interfaces necessary to record the above characteristics with the required resolution and at the specified intervals in a Government approved test plan.

11-4.10 CONTROLLABILITY

Controllability testing should be conducted by the Government testing activity to determine three characteristics:

1. Sensitivity, defined as the maximum angular acceleration (degrees/second) of the air vehicle per 2.54 cm (one inch) of deflection of a cockpit control, as well as time to reach that maximum acceleration
2. Response, defined as the maximum angular velocity (degrees/second) per 2.54 cm (one inch) of deflection of a cockpit control, as well as time to reach that velocity
3. Control power, defined as the attitude change one (1) second after a 2.54 cm (one inch) control displacement. Using mechanical stops to ensure precise inputs, sudden, near-step inputs are applied to the trimmed controls. This input is maintained until maximum acceleration is attained or recovery is required. These inputs should be applied with a controlled buildup to maximum control deflections if possible.

The range of controllability testing should include hover and forward flight testing as specified by the PA.

ADS 33D-PFR (Ref. 10) covers controllability characteristic criteria in Section 3.6, and precision and aggressive maneuvers to be tested are in Sections 4.1 and 4.2 of that same publication. Collection of airframe damping information at various frequencies should normally be included in the testing.

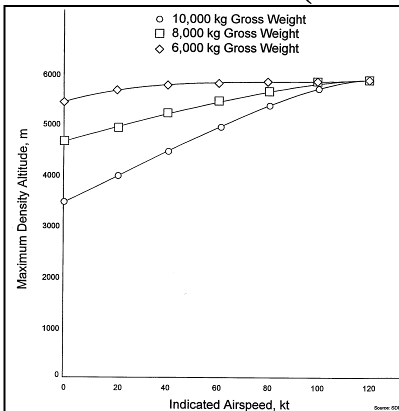


Figure 11-7 Transition Lift and Control (acceptable at all nacelle angles)

Characteristics to be measured include indicated and boom airspeed; pressure altitude; OAT; fuel weight; rotor speed; longitudinal, lateral, and directional control displacement and force; collective (thrust) displacement; sideslip angle; normal acceleration at pilot's station and CG; rate of climb or descent in turns; and pitch, roll, and yaw rates and attitudes. Instrumentation requirements may include oscillograph, magnetic tape, or computerized data acquisition interfaces necessary to record the above characteristics with the required resolution and at the specified intervals.

Typical graphical data outputs for lateral inputs, control sensitivity, and damping versus frequency are included in Figures 11-8, 11-9, and 11-10. Acceptable control sensitivity and response is dependent upon air vehicle type and mission requirements and is generally specified by the PA.

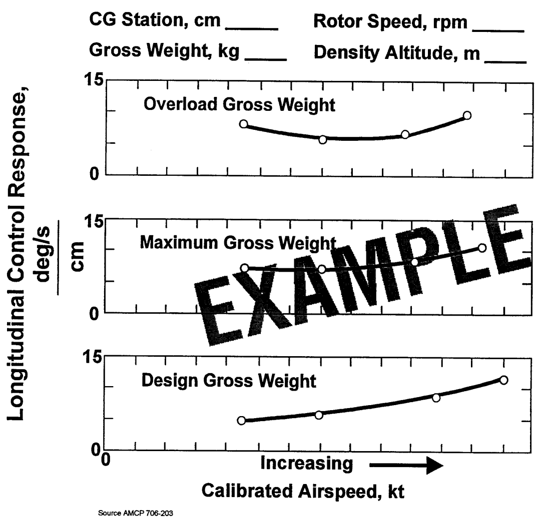


Figure 11-8 Control Response

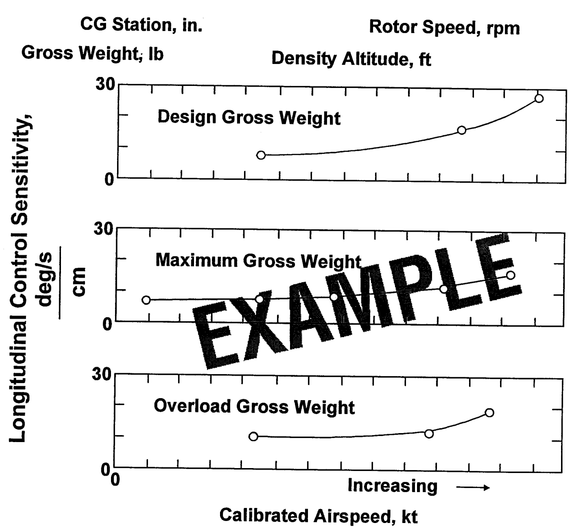


Figure 11-9 Control Sensitivity

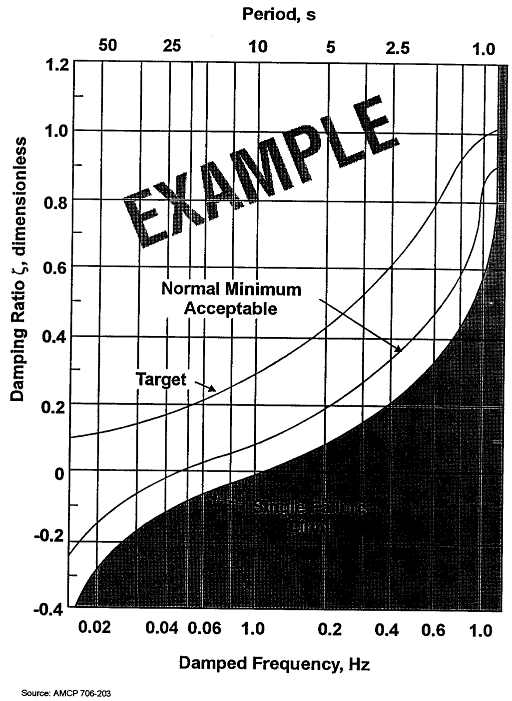


Figure 11-10 Frequency Damping Characteristics

11-4.11 NOVEL CONTROL SYSTEMS

As discussed in par. 11-3.4, the advent of fly-by-wire and fly-by-light (fiber optic) flight controls means that there might be no direct mechanical linkages between the pilot's controls and rotor and control surface actuators, and measurement of control displacements or forces might not be an accurate method of evaluating pilot control inputs. Force-feel controls further complicate this arrangement. With these controls in trimmed flight, a force-feel control can be displaced and released to return to neutral, with the new actuator position being a new control displacement. Generally, the displacement of the actuator should be some function of the force applied and the duration of the application. In trimmed flight, the control could be displaced for some period of time, driving the actuator to a new position, released and allowed to return to neutral (no force applied), and the attitude should change to a new value with the same stick position. In this way, all graphical plots shown in this chapter would have the same stick position. However, if actuator position is recorded, those positions plotted along the vertical axes would more accurately reflect static and dynamic stability characteristics.

When evaluating novel control systems, human error during flight testing has already been mentioned as a potential problem. If several controls are integrated into one control stick, pilot attempts to provide input in only one axis must be closely monitored to ensure that no coupled inputs (cross controlling) are inadvertently introduced into flight testing. An example might be a sidearm controller which incorporates longitudinal, lateral, and yaw control for rotorcraft into one stick. In attempting to check inputs in the longitudinal axis, the pilot's arm and wrist might inadvertently induce lateral inputs and a yawing moment to the air vehicle data collection requirements should be very similar to mechanical linkage control systems with the exception of control positions. Actuator positions or some other alternate means of measuring the commanded inputs to the control surfaces, rotors, and propellers should be determined by the test activity based on the testing requirements. In some cases, the effect of a given force application for a given duration may have to be verified. This is discussed in subpar. 11-3.4.

Instrumentation should also be similar to that required for conventional control systems, with the exceptions of requirements to measure actuator displacements and control forces, and may include oscillograph, magnetic tape, or computerized data acquisition interfaces necessary to record the characteristics with the required resolution and at the specified intervals in a Government approved test plan.

11-4.12 AIRWORTHINESS AND FLIGHT CHARACTERISTICS (A&FC) REPORT

The A&FC report is a formal type of test report, which usually contains a complete evaluation of the handling and performance characteristics of the air vehicle. Refer to para. 11-4 for A&FC test information. The report is used to provide test data and information for the operator’s manual. Also, the report is used to identify and document deficiencies (if any), shortcomings, and non-compliance with specifications. Deficiencies must be corrected before an air vehicle can be fielded. The procedures and reports that apply to the A&FC are the same that apply to the PAE specified in subpar. 11-3.8.

11-5 CLIMATIC TESTS

Adverse climatic conditions, such as those found in arctic, desert, and wet tropical areas should be expected to affect military systems and equipment. Extreme heat and cold, as well as adverse conditions such as sand and salt spray might reduce system and equipment performance capabilities, such as a reduction in response time, etc. Also, extreme climatic conditions might impact the functionally of systems and equipment by causing components to stick, jam, or otherwise fail, or might impact usability because of limitations of the crew caused by required clothing items required to protect individuals from these conditions. MIL-STD-210, *Climatic Information to Determine Design and Test Requirements for military Systems and Equipment* (Ref. 15) or equivalent handbook will provide both climatic data that can be used to derive design and test criteria for military systems and equipment and environmental data for climatic conditions which military equipment can be expected to encounter. AR 70-38, *Research, Development, Test and Evaluation of Materiel for Extreme Climatic Conditions* (Ref. 16), contains guidance for determining climatic conditions in the research, development, test, and evaluation of materiel (such as air vehicle systems and aviation materiel) used in combat. Air vehicle systems developed by the Army should be designed to operate in specified climatic design types as shown in TABLE 11-1. Climatic tests should be performed under simulated conditions in a laboratory environment (engineering tests) for the required climatic design type and operational conditions specified in AR 70-38 (Ref. 16) for which the materiel was designed. The engineering tests are conducted to identify design and operational deficiencies. Chapter 9 contains information on climatic laboratory tests usually performed by the contractor. Following the engineering tests, and correction of deficiencies, developmental testing by TECOM should be conducted under natural environmental climatic conditions at the

Climatic Design Type	Daily Cycle (QSTAG 360 Equivalents)*	Operational Conditions			Storage and Transit Conditions	
		Ambient Air Temperature °C (°F)	Solar Radiation W/m² (Bph)	Ambient Relative Humidity %	Induced Air Temperature °C (°F)	Induced Relative Humidity %
Hot	Hot-Dry (A1)	32 to 49 (90 to 120)	0 to 1120 (0 to 355)	3 to 8	33 to 71 (91 to 160)	1 to 7
	Hot-Humid (B3)	31 to 41 (88 to 105)	0 to 1080 (0 to 343)	59 to 88	33 to 71 (91 to 160)	14 to 80
Basic	Constant High Humidity (B1)	Nearly Constant 24 (75)	Negligible	95 to 100	Nearly Constant 27 (80)	95 to 100
	Variable High Humidity (B2)	26 to 35 (78 to 95)	0 to 970 (0 to 307)	74 to 100	30 to 63 (86 to 145)	19 to 75
	Basic Hot (A2)	30 to 43 (86 to 110)	0 to 1120 (0 to 350)	14 to 44	30 to 63 (86 to 145)	5 to 44
	Basic Cold (C1)	-21 to -32 (-5 to -25)	Negligible	Tending toward saturation	-25 to -33 (-13 to -28)	Tending toward saturation
Cold	Cold (C2)	-37 to -46 (-35 to -50)	Negligible	Tending toward saturation	-37 to -46 (-35 to -50)	Tending toward saturation
Severe Cold	Severe Cold (C3)	-51 (Cold soak) (-60)	Negligible	Tending toward saturation	-51 (-60)	Tending toward saturation

*Designations in parentheses (A1, A2, B1, B2, B3, C1, C2, and C3) refer to corresponding climatic categories in Quadripartite Standardization Agreement 360 Climatic Environmental Conditions Affecting the Design of Military Materiel.

Table 11-1 Summary of Temperature, Solar Radiation, and Relative Humidity Daily Cycles appropriate TECOM developmental test facilities (arctic, tropic, desert, etc.). The developmental tests conducted by TECOM are an extension of the engineering tests and allow for testing of equipment that functions only in the natural environment such as landing skis and Aviation Life Support Equipment (ALSE).

The climatic engineering tests, which are a prerequisite for the natural environmental tests, should be conducted on prototype or production air vehicle. When warranted, the tests may be repeated for production items. Air vehicle system tests should be conducted to evaluate the total effectiveness and operational procedures throughout a predetermined range of conditions. The subsystem effectiveness and operation should be evaluated at the same conditions, and the results used to:

1. Demonstrate adequate safety of operation so that flight releases may be issued for the climatic developmental tests

2. Determine compliance with applicable specifications

3. Formulate necessary recommendations for design changes to maintain acceptable performance standards throughout the operational range.

The most suitable facility for simulating the natural environmental test conditions is the USAF Climatic Laboratory located at Eglin AFB, Florida. Normally, the prime air vehicle contractor has the overall responsibility for the climatic laboratory engineering test. The requirements for the climatic laboratory testing performed by the contractor are contained in subpar. 9-9. The PA should provide the test pilots and the test engineers (usually from TECOM) who should conduct the tests. When required, climatic laboratory reevaluations or retests will normally be performed by the procuring activity without contractor participation.

11-6 SURVIVABILITY TESTS

The objectives of survivability testing should be to identify inherent vulnerabilities and effectiveness of equipment countermeasures. Air vehicle level survivability testing could be accomplished by a contractor or by the Government with contractor support. Depending on the contractor and contract, it often might be more feasible to accomplish this testing at Government test facilities. Elements of system level survivability testing are:

1. Susceptibility Reduction Testing. Inherent signature should be determined by test. Design improvements and aircraft survivability equipment (ASE), if any, should then be tested to demonstrate effectiveness. See subpar. 11-6.3 “Special Electromagnetic Interference (SEMI)” and subpar 11-6.4 “Electronic Warfare" for testing of countermeasures and counter countermeasures.

2. Vulnerability Hardening Testing:

a. Ballistic Hardening. Live fire testing of armor and weapons platform should be accomplished as discussed in ADS 11, *Survivability Program. Rotary Wing* (Ref. 17), and as further discussed in subpar. 11-6.1 “Live Fire."

b. Directed Energy Hardening. Testing should be accomplished to demonstrate hardness against lasers, high power microwave, and radio frequencies, as discussed in ADS 11 (Ref. 17) and DA PAM 73-series (Ref. 2).

3. Nuclear Hardening. Nuclear simulation tests should be conducted. The ground test vehicle, static test article, or other functional mockup should be tested to demonstrate hardening against nuclear electromagnetic pulse, thermal, gamma, and blast as discussed in ADS ll (Ref. 17) and DA PAM 73-series (Ref. 2).

4. Nuclear, Biological, and Chemical (NBC) Hardening. Simulation testing should

be accomplished as discussed in ADS 11 (Ref. 17) and DA PAM 73-series (Ref. 2).

5. Crashworthiness Testing:

a. Crash Avoidance (Aircraft Level Tests). Testing should be conducted to demonstrate the effectiveness of wire cutters and similar devices, as discussed in ADS ll (Ref. 17).

b. Crashworthiness (Aircraft Level Tests). Testing should be conducted to demonstrate overall air vehicle crashworthiness, as discussed in ADS ll (Ref. 17). See discussion and criteria in subpar. 11-6.2 Crashworthiness."

DoDR 5000.2-R (Ref. 4) cites Title 10, United States Code, Section 2366 which requires "...survivability testing and lethality testing on covered major systems and product improvement programs that significantly affect the survivability of a covered weapons system before full-scale production." The term "covered system" means a vehicle, weapon platform, or conventional weapons system that includes features designed to provide some degree of protection to users in combat and is a major system.

Prior to any survivability testing activities, the air vehicle contractor (AC) and PA should agree on the air vehicle damage measures to be applied. Supplemental descriptions and criteria for live fire, crashworthiness special electromagnetic interference (SEMI), and electronic warfare are given in the subparagraphs that follow.

11-6.1 LIVE FIRE

The scope and nature of live fire are described in par. 11-6. Prior to any actual firing tests, analyses should be performed by the AC to identify vulnerable components and subsystems and maximize the efficiency of live fire testing. The System Threat Assessment Report/System Threat Assessment (STAR/STA) is the basic threat document defining the threat environment in which the development system should function. If required by the PA, actual live fire tests (LFTs) should be performed on those components with either actual or simulated surrounding structures and components.

Four elements of ballistic survivability testing might be tested by the Government. These elements are armor, ballistic tolerant structure, and components positioning and separation of subsystems, and fuel ballistic protection. Contractor testing and analyses in these areas is described in par. 9-14.

Threat projectile, impact location, obliquity, tumble, and striking velocity should be specified in Government test plans, and should be recorded and reported for all firing tests. Another element of LFT, lethality, is primarily related to weapons systems effectiveness testing which was also covered in Chapter 9.

Compatibility of armor with typical operators and maintainers should be validated by Government use personnel prior to beginning LFT. Validation is intended to confirm that armor installed in its normal position does not interfere with critical operator and maintainer tasks. If battle damage assessment and repair (BDAR) is a requirement, such repairs should be validated using LFT assemblies and components to demonstrate specification compliance.

Since only vulnerable areas should be tested, measures of the air vehicle airworthiness and mission effectiveness are primarily related to probabilities of suffering a specific type of kill such as attrition, mission abort, or forced landing kills, and may be expressed as the probability of a kill given a hit (PK/H). Instrumentation required to monitor these tests may include video recorders, instruments for monitoring electrical and functional parameters, such as current, torque, and temperatures, and pressure transducers for monitoring transient fluid and blast pressures.

11-6.2 CRASHWORTHINESS

Contractor testing to determine fuel system and crew station crashworthiness and to perform landing gear drop tests is covered in subpars. 8-3.5, 8-11.3, and 8-6.1, respectively. However, total crashworthiness of the system depends upon the likelihood that crew or occupants will either be subjected to acceleration forces in excess of human tolerance or be susceptible to injury by objects invading their stations. Such objects may be either static components displaced by impact or dynamic components which have been broken loose upon impact. If required by the PA, Government testing may involve subjecting a complete air vehicle or representative fuselage to impacts under various conditions. These conditions may include, but not be limited to, various rates of descent, impact angles relative to the fuselage, and percentages of lifting forces applied. Due to the possible danger of such tests, these impacts should not be staged with human subjects. The testing should be accomplished with instrumented, anatomically similar crash "dummies" capable of measuring accelerations, forces at critical parts of the body, and movement of limbs in the simulated crash. Landing gear, critical structural members, and crashworthy seating may also be instrumented to record displacements and stresses during the crash sequence, allowing an estimate of the energy attenuation properties of the landing gear and supports, fuselage, and seating. Video recording of the cockpit and cabin interior during the crash sequence is also desirable.

To conserve test articles, testing should begin conservatively at lower impact angles and velocities and 100 percent lift. In this way, several recordings of increasingly more severe crash data can be made before damage occurs. In this way, an estimate of survivable crash accelerations and velocities can be made, and the data can be incorporated into the operator's manual.

11-6.3 SPECIAL ELECTROMAGNETIC INTERFERENCE (SEMI)

SEMI involves the possible electromagnetic countermeasures that might capitalize on vulnerabilities. While SEMI is not a part of ADS 37A-PRF *Electromagnetic Environmental Effects (E3). Performance and Verification Requirements*, (Ref. 18), it might avail itself of some of the information generated as a result of ADS 37A-PRF testing. As such, SEMI testing might be more appropriately included with electronic warfare (EW) testing.

11-6.4 ELECTRONIC WARFARE

Government testing of EW capabilities for air vehicles may include an evaluation of electronic countermeasures (ECM), and testing of electronic counter-countermeasures (ECCM) capabilities. Typically, it might involve effectiveness testing of the air vehicle and mission equipment for self defense. However, it could also involve effectiveness testing of the air vehicle, target acquisition equipment, and weapons as a total system. These evaluations are similar to the contractor evaluations of par. 9-14. Analyses and testing might be performed to determine:

1. Probability of detection (P_D) by a particular threat at the specified range
2. Probability of classification given detection ($P_{C/D}$) by the threat as correct type of target

3. Probability of engagement given classification ($P_{E/C}$)

4. Probability of hit given engagement ($P_{H/E}$)

5. Probability of kill given a hit ($P_{K/H}$). $P_{K/H}$ is the only one of these parameters not effected by EW characteristics.

As an example of EW testing, the Government might require effectiveness testing of signature control in the acoustic and electromagnetic spectrums as part of the performance measurements of air vehicle survivability. Reduced signatures can mean lower PD, $P_{C/D}$, $P_{E/D}$, and $P_{H/E}$. These signatures may be calculated by computer simulation or analysis, but, if required for specification compliance by the PA, may be subject to verification by flight testing. With the exception of acoustic signatures, all other signatures are dependent on detection of electromagnetic emissions or reflections in some portion of the electromagnetic spectrum.

Testing could involve assessment of probabilities of detection PD, classification Pc, and engagement PE, for specified threats or threat simulators at various ranges. If emission control (EMCON) is a requirement, these tests should be conducted in normal and EMCON mode. Maneuvering flight should be required during the tests if maneuvers can be shown to effect the probabilities of detection, classification, and engagement.

Further Government testing of ECM and ECCM should be conducted to verify ASE effectiveness. ASE is typically categorized as threat sensors and countermeasures. Examples of ASE are infrared (IR) jammers, radar jammers, radar warning receivers, and decoys. Additional survivability features which can aid in defeat of threats using the electromagnetic spectrum include low reflective paint and IR exhaust suppressers. Only the first four examples are described. IR jammers include electrically fired and fuel fired countermeasures sets which are designed to confuse or decoy threat IR guided missile systems. When used in conjunction with low reflective paint and IR exhaust suppressers, these jammers provide jamming of all known threat IR missile systems.

Radar jammers include countermeasures sets designed to detect and protect against both pulse and continuous wave (CW) illuminator radars. Pulse illuminator radar jammers are designed to respond to the most critical threat weapons systems anticipated to be encountered by attack rotorcraft in a hostile environment, while CW radar jammers protect against surface-to-air missiles (SAM) and airborne intercept missiles (AIM).

Radar warning receivers also are designed for pulse and CW illuminator radars. Additionally, there are missile approach detectors which detect the approach of IR guided missiles.

Decoys take the form of flares dispensed to confuse or mislead IR guided missiles, and chaff canisters or cartridges which prevent radar-controlled artillery from detecting, hitting, and destroying the air vehicle dispensing chaff.

The PA should define air vehicle survivability equipment (ASE) effectiveness testing to be conducted by the testing activity. These plans should identify threat systems or simulators to be provided by the PA, and should be subject to approval by the PA. Prior to testing ASE, the PA should provide the AC-established baseline susceptibility or vulnerability of the air vehicle to specified threat weapons systems when not using ASE. This should be done initially by analysis, and verified by flight test using controlled maneuvers, altitudes, and air vehicle configurations. Typical measures would be $P_{C/D}$, $P_{E/C}$, and, possibly, an analytical determination of $P_{H/E}$ without use of ASE. Threat systems or threat simulators may be used to establish the baseline characteristics and to perform effectiveness testing.

Once the baseline characteristics are established, the Government may repeat required flights and testing necessary to determine the reduction in susceptibility or vulnerability (increase in survivability) due to the use of ASE. Any limitations, such as electrical power, maneuvering, or range, brought about by use of ASE should be verified during this testing.

11-7 ELECTROMAGNETIC ENVIRONMENTAL EFFECTS

Other tests that are conducted by the Government at Government test facilities with contractor support are

1. Electromagnetic vulnerability (EMV)
2. Hazards of electromagnetic radiation to ordnance (HERO)
3. Electromagnetic radiation hazard (EMRH)
4. Streamering and included effects lightning
5. Static electricity
6. Emission control (EMCON).

Performance and verification requirements are discussed in ADS 37A-PRF (Ref. 18). Also, the facilities of the US Army Test and Evaluation Command needed for these tests are described in DA PAM 73-series (Ref. 2). The Government has the test facilities and contractors generally do not.

11-8 DEVELOPMENTAL TESTS (DT)

The DT is performed in controlled environments by specially trained individuals to assess the adequacy of the system design, to determine compliance with system specifications and critical technical parameters, determine if the system is ready to enter the next acquisition phase, and to determine how safe the system is for operation by user troops and civilians. Much of the information upon which independent evaluations and assessments are based consists of data generated during testing. The AR 73-1 (Ref. 1) requires implementation of a continuous evaluation process in order to streamline development and to minimize the requirement for duplicate Government tests. Broader objectives of D_T are:

1. Assist the engineering design and development process
2. Verify performance objectives and specifications
3. Demonstrate that design risks have been minimized
4. Estimate the system's military utility when introduced
5. Evaluate the compatibility and interoperability with existing or planned equipment and systems
6. Provide an assurance that the system and equipment are ready for testing in the operational environment.

11-9 OPERATIONAL TESTS (OT)

Operational testing involves estimation of the operational effectiveness and suitability of a new air vehicle for use. Operational testing can be conducted before full scale development (FSD) as an early operational assessment (EOA), during FSD as part of operational test and evaluation (OT&E), or after deployment as a part of follow-on test and evaluation (FOT&E). The following paragraphs describe the two critical areas of operational testing; issues and objectives, and resources and test conduct and reporting requirements.

11-9.1 ISSUES AND OBJECTIVES

The basic objective is to determine if the air vehicle satisfies the performance requirements of the Operational Requirements Document (ORD). The TEMP should describe issues and criteria for operational testing. For additional information see AR 73-1 (Ref. 1) and DA Pamphlet 73-series (Ref. 2). Operational issues should be few in number, encompass the total system, focus on the system mission, be operationally relevant, and be realistic (to system maturity) for the supported decision. The specific objectives of the operational tests should be designed to obtain data to address the operational issues. This includes; but, is not limited to include:

1. Obtaining quantitative information on which to base milestone decisions
2. Estimating the operational effectiveness and suitability of the system
3. Identifying needed modifications and improvements
4. Providing information on tactics, doctrine, organization, and personnel requirements
5. Providing data to determine the adequacy of technical manuals, handbooks, plans, and documentation effectiveness for operation and support of the system.

11-9.2 RESOURCES AND TEST

Operational tests may require a large amount of resources to adequately conduct the test. Typical military operators and maintainers are required for conduct of operational tests. Other service's air vehicles may be required for aerial refueling and transportability testing, and naval ships may be needed for shipboard compatibility and dynamic interface testing. Also, adequate facilities, fuel, and logistic support will be needed. Other air vehicles may be required for a baseline comparison. Threat simulators or actual threat systems may be required for survivability testing.

The EOA should be conducted on a prototype air vehicle, the OT&E should be conducted using an early production air vehicle, and the FOT&E should be conducted using later production air vehicles, possibly with product improvements incorporated to correct deficiencies discovered in earlier operational tests. Operational tests should be conducted in an environment as close to a natural environment as possible to include representative friendly units, support structure and equipment, and enemy threat vehicles. The tests should also be conducted using the anticipated or known tactics and doctrine of friendly and enemy forces. For each operational issue identified in subpar. 11-9.1, the tester should have either qualitative or quantitative measures identified, a means for collecting the required information, a means for analyzing the data (as needed), and a means for drawing conclusions.

11-9.3 REPORTS

Test reports should reference the test plan or request. Significant findings and information concerning the objectives of subpar. 11-9.1 should be submitted at the end of each phase of testing. The general content of a operational test report should include a statement concerning the operational effectiveness and the operational suitability of the tested system. The report should also include supporting data for the conclusions inferred from the test. Classified data must contain the proper security classification on each page of reports, etc. Distribution of the report should be as specified in the test request and should satisfy the requirements of Department of Defense Directives Number 5350.24, *Distribution Statements on Technical Documents* (Ref. 19) and Number 5230.25, *Withholding of Unclassified Technical Data* *from Public Disclosure* (Ref. 20). Normally, these test reports should be submitted at least 45 days prior to milestone decision points.

11-10 FOLLOW-ON EVALUATIONS (FOE)

As mentioned before, FOT&E may be conducted to evaluate modifications or improvements, or may be conducted solely to verify that earlier operational testing accurately evaluated operational effectiveness and suitability. An FOE to evaluate modifications or improvements usually can be conducted using tailoring of requirements, which would result in a significant reduction in resource requirements. An FOE conducted to verify earlier operational test results generally would require the same assets, and be conducted in a similar manner to the original test.

11-10.1 ISSUES AND OBJECTIVES

These issues and criteria revolve around the questions of operational effectiveness and operational suitability. The objectives of the FOE are to:

1. Obtain another estimate of the operational effectiveness and suitability of the system in selected areas
2. Identify additional needed modifications and improvements
3. Provide further information on tactics, doctrine, organization, and personnel requirements.
4. Provide information for reprocurement

11-10.2 RESOURCES AND TEST CONDUCT

Personnel resources for FOE are the same as for EOA and OT&E. Other service air vehicle, naval ships, and/or threat simulators or actual threat systems may be required if deficiencies or improvements involve those areas. As mentioned before, FOE should be conducted using later production air vehicles, possibly with product improvements incorporated to correct deficiencies discovered in earlier operational tests. Test methods for an FOE is similar to methods used for EOA and OT&E, and should include tests conducted using natural environments, threat and friendly forces, and current tactics and doctrine.

11-10.3 REPORTS

Test reports should reference the test plan or request. Test reports detailing significant findings and information concerning the FOE objectives should be submitted at the end of FOE. Test reports should contain conclusions and supporting documentation on the operational effectiveness and suitability of the system. Normally, these test reports should be submitted at least 45 days prior to the final decision to enter low rate initial production (LRIP). Classification and distribution should be as provided for in subparagraph 9-11.3.

11-11 GOVERNMENT SOFTWARE TEST AND EVALUATION (T&E)

Government qualification of software should only be required when the government is the developer of software, for military unique hardware and software, and for modifications to government developed and qualified hardware and software. Government qualification should not be required for commercially developed software and reuse of software.

The contractor should be totally responsible for satisfying both hardware and software performance requirements of the contact; however, to satisfy its' interest in airworthiness and flight safety, the

Government software T&E is concerned with the test activities of all life cycle phases of the software portions of weapon systems computer resources (WSCR). Because each logical element of embedded software cannot be tested at a system, subsystem, hardware configuration item (HWCI) or possibly even computer software configuration item (CSCI) level, testing should occur during every phase of a development to maximize thoroughness and eventual reliability. The Government's level of involvement in each of these various test phases is dependent upon:

1. Criticality (flight safety versus mission essential versus non-essential)
2. Complexity (design and algorithms)
3. Platforms (embedded avionics versus automated test equipment)
4. The nature of the software's use (application and frequency)
5. Available resources (primarily manpower).

11-11.1 INTEGRATED PRODUCT TEAM (IPT) - SOFTWARE

The IPTs are an integral part of the defense acquisition oversight and review process. For additional information see DoDR 5000.2-R, *Mandatory Procedures for Major Defense Acquisition Programs (MDAPs) and Major Automated Information System (MAIS) Acquisition Programs,* (Ref. 4). Software is an important consideration for these teams. The Working Level IPTs (WIPTs) typically will meet as required by the program, project, or product management office (PM) to help the PM plan program structure and documentation and resolve issues. The IPT should provide a forum for review and resolution of issues impacting the acquisition, development, and support of the weapons system. These issues should include; but, not be limited to include, computer hardware and software. The IPT should include representatives from each of the following: Air vehicle contractor, MATDEV command, combat developer command, each test and evaluation command and the designated life cycle engineering center (LCSEC). The organizations and their IPT software test related roles are described below:

1. The air vehicle contractor as the developer of computer hardware and software is responsible for design, development, test, and evaluation.
2. The materiel developer is the command or program, project, or product management (PM) office which has overall program and management responsibility for the execution of the software development, testing, and fielding. With assistance from associate members, the MATDEV is responsible for ensuring that adequate testing is performed on the software while also striving to reduce T&E costs and shorten test schedules to the maximum extent possible. This should be accomplished by integrating test requirements, eliminating test redundancy, and early identification of potential problem areas in the software during the T&E program. MATDEV command matrix support organizations may provide support to the IPT on behalf of the MATDEV.
3. The combat developer (CBTDEV) represents the user and trainer in the preparation of system level requirements and critical operational issues and criteria (COICs). The principal CBTDEV function relative to testing is to ensure that changes to software requirements due to test phase activities do not adversely impact user doctrine, tactics, or other system level requirements.
4. The testers and evaluators are the representatives from the commands providing the technical testers who review and verify contractor and Government test

plans, technical independent evaluators who prepare independent evaluation plans and reports, operational testers who assist in the identification and elimination of redundant testing and are responsible for the preparation of test evaluation plans and the conduct of operational tests and reporting their results, and operational independent evaluators who assist in problem identification and redundant tests elimination.

5. The designated LCSEC is the software engineering center appointed to be responsible for computer resources development and support of the system to be procured. The principal IPT functions of the LCSEC relative to testing are to ensure that test policies, standards and methodologies are contractually adapted and adhered to in order to ensure procurement of high quality, supportable software products and documentation.

11-11.2 CONTRACTOR SOFTWARE QUALIFICATION TESTS

An open systems approach should be followed for all system elements (mechanical, electrical, and software, etc.) in developing systems. This approach is a business and engineering strategy to choose specifications and standards adopted by industry standards bodies or defacto standards (set up by market place) for selected system interfaces (functional and physical, products, practices and tools; however, contractor qualification of software typically involves a structured series of informal and formal tests conducted throughout the development. The DoD-STD-498 (Ref. 5) contains relevant information; however, this standard may not be specified as a requirement without a waiver.

Informal tests range from individual developer tests through build release tests of CSCIs and can occur on any of the following hosts:

1. Developers desktop or workstation
2. Test benches
3. System integration facilities.

Informal testing comes with a multitude of "built-in" evaluators because integration of software also requires the interaction of software developers. This interaction of software developers during the integration phase provides an early evaluation of system software implementation. Integration forces developers to continually review and evaluate their own products as well as those of others with whom their products must integrate. The degree of evaluation varies from evaluating the lines of code to verifying system performance at the air vehicle level. Rarely is it desirable for the Government to contract for detailed data and reports from these informal test activities and evaluations.

Formal testing is defined as tests which are conducted in accordance with test plans and procedures and witnessed by an authorized PA representative.

A brief synopsis of the various test phases follows.

1. Computer software unit (CSU) tests. CSU tests are informal tests for which the procedures and results are documented in contractor CSU software development folders (SDFs). Resultant changes to the code, documentation and retesting results should be updated in the CSU SDFs. Each decision branch of the software logic should be correctly exercised at least once for each possible outcome.

2. Computer software component (CSC) tests. CSC tests are informal tests of integrated CSUs for which the procedures and results are documented in contractor CSC SDFs. These tests should additionally stress the limits of the code. Resultant

changes to the code, documentation and retesting results should also be updated in the CSC SDFs.

3. CSCI informal tests. CSCI informal tests are tests of integrated CSCs performed prior to formal testing. The test plans, test cases and test results should be documented in contractually required STPs, STDs and STRs. However, prior to formal tests, this information is recorded in the CSCI SDFs. Resultant changes to the code, documentation and retesting results are again updated in the CSCI SDFs.

4. CSCI formal tests. CSCI formal tests are the CSCI tests identified in the STDs that should be witnessed by the Government. The qualification requirements for the CSCIs being tested are those identified in the SRSs. The approved procedures are those in the STPs and STDs. The results are documented in the STRs.

5. System integration tests. The contractor's software organization may utilize system integration facilities for both informal and formal tests.

11-11.3 GOVERNMENT WITNESS OF SOFTWARE VALIDATION

Validation is the evaluation process that determines if the software execution correctly satisfies functional requirements. Typically, it is an end-to-end verification that the code implementation meets the performance requirements. Verification is the term used to state that each incremental phase of a development has successfully and correctly been accomplished to allow transition to the next phase.

Throughout the development activities, the Government should maintain enough insight into the actual software development activities that traceability between requirements and code can easily be verified. The Government should be confident that the path through which the established requirements have been implemented has been satisfactorily verified such that only an end-to-end validation of SRS requirements is needed.

If resources allow Government personnel to work side by side with developers and testers during development and informal testing, then this is a reasonable possibility as well as a valuable source of data. Otherwise, the Government is relegated to simply observing test compliance with STPs and STDs, and reviewing resultant STRs.

11-11.4 GOVERNMENT SOFTWARE QUALIFICATION

Government qualification of software should only be required when the government is the developer of software, for military unique hardware and software, and for modifications to government developed and qualified hardware and software.

The main difference between contractor and government qualification is the more active role that is played by the Government and the added importance of configuration management for the baseline product. The configuration management issue during LCSS should not only address product configuration, but should also be concerned with managing software change requests (SCR), new tests results, and resultant regression testing results.

Equivalent informal test activities should occur in either environment. These are accomplished at various stages throughout the development with testing at the CSU, CSC and CSCI levels. Formal qualification testing is also equivalent among the two environments with the exception of the additional regression testing requirements of the LCSS phase. These will be discussed in subpar.
11-11.5.

11-11.5 LIFE CYCLE SOFTWARE SUPPORT (LCSS) TESTS

In the LCSS role, independent verification and validation (IV&V) tests are conducted to verify new functions and implementation of SCRs. The objective of these tests is to confirm that functions, that were previously performing correctly, continue to perform correctly after a change has been made. The scope of testing required for LCSS tests is dependent on the extent of the change and the potential impact of an undetected error. Regression testing is conducted to verify correction of software trouble reports (STRR) and to ensure integrity of previously established baselines. Following IV&V testing, integration and test (I&T) is conducted using system hardware and software. If subsystems are unavailable at I&T, they are usually simulated. Interface testing should be conducted on failed, new, and modified subsystems. This testing should include checking all interface parameters as described in the interface control document. Rehosted software is software that is modified so that it operates on a different host computer. Testing of rehosted software may require extensive retesting if an undetected error could result in injury or death.

Progress towards satisfactory qualification can be measured by examination of metrics pertaining to the status of "open" SCRs and STRRs, and in the results of STRs. It must be noted that the most detailed DT&E of software occurs at the individual programmer level which is significantly lower than the system evaluator's level. Therefore, the system evaluator does not have as intimate a knowledge of the intricacies of the software; this lack of knowledge can contribute to STRRs being written for errors where none actually exist.

As in all system test situations involving software (and particularly in an LCSS situation), follow-on system level testing may not fulfill expectations. If this occurs, a determination should be made as to whether the cause is requirements, hardware, or software-based. Consequently, an iterative process results with eventual resolution and completion of qualification at all levels.

11-12 SYSTEM CALIBRATIONS

The calibration of instrumented parameters required for performance, handling qualities, and other types of flight testing must be highly accurate. Calibration is the procedure used to check, adjust, or systematically standardize the graduations of a quantitative measuring instrument. Typical measurements required for flight testing are airspeed, altitude, attitudes, rates, accelerations (both air vehicle and pilot seat), stick and pedal positions, total and free air temperature, fuel quantity, engine power parameters, rotor speed and torque, and vibration. Special calibrations are used for boresighting systems such as armament, target acquisition designation (TAD), and forward looking infrared (FLIR). Calibrations of navigational equipment, such as inertial, requires tilt tables and other special equipment. Calibration intervals are established based on parameter history, the importance of the parameter, and on what test is being conducted. Each parameter should have established and agreed to specifications for engineering units, range, accuracy, resolution, sample rate, frequency response, time phase relationships, scaling, and calibration well in advance of testing. Government witnessing of calibrations should be conducted.

A typical instrumentation measurement consists of a transducer, a signal conditioning module, and a record module which may be separate components or combined as one or more units. These components together constitute a system that should be calibrated. The transducer converts the parameter (speed, position, angle, rate, acceleration, temperature, RPM, flow, frequency, etc.) to a recordable signal such as a voltage or digital output. These components should be calibrated as a system on the aircraft, with the signals recorded by the air vehicle recording system, and the recorded data decomutated and scaled by the data processing system that should be used for processing final data. Calibrations are accomplished as required based on the calibration history of each parameter.

Digital recording techniques should be used to prevent measurement accuracy degradation during data recovery. Other FM modes, such as narrow band, constant band, and wide band can be used for cases where time phasing or very high frequencies are important. Multiplex or fiber optic databus data are also used for flight test instrumentation. Early in the development process, flight test instrumentation is used to establish the accuracy of the bus data.

Data sampling is another accuracy consideration. Simultaneous sampling of all parameters is desirable goal but usually does not exist. If a time phase relationship exists between parameters presented in a time history tabulation (or plot) or in a multi-measurement calculation, the accuracy obtained in the individual parameters can be lost.

Records of all component and system calibrations should be maintained in a database and comparisons made to prior calibrations. Calibration at several temperatures or at the expected transducer operating temperature may be required in some cases because temperature is often the major factor in measurement error. When strain gage or bridge type transducers (loads and some pressure transducers and accelerometers) are used, wiring lengths can introduce error. These errors are calculated and corrections applied or they are eliminated by a system calibration.

Pitot static calibration is required to be performed early in the flight test program to determine the position error of the system and to establish the accuracy of airspeed and altitude data for all flight conditions to be tested. Several methods may be used to calibrate the pitot static system, to include ground speed courses, and calibrated "trailing bomb" devices. Trailing bombs are devices which have their own pitot and static ports, and have been calibrated in a wind tunnel. This calibrated device is then connected to the air vehicle using cables and tubing and flown at varying airspeeds. The test air vehicle pitot-static data is then corrected to the results provided by the "trailing bomb." The pitot static system calibration may also be conducted in formation flight using another air vehicle with predetermined and known position error corrections.

The instrumentation calibration data are expressed as slope intercepts, table lookups, or a curve fit and applied to the flight test recorded data.

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None

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LIST OF ABBREVIATIONS AND ACRONYMS

A&FC	=	airworthiness and flight characteristics
ADOCS	=	advanced digital optical control systems
ADS	=	aeronautical design standard
AFB	=	air force base
AIM	=	airborne intercept missile
ALSE	=	aviation life support equipment
AR	=	army regulation
ARL	=	army research laboratory
ASE	=	air vehicle survivability equipment
AT	=	acquisition team
ATCOM	=	aviation and troop command
AWR	=	airworthiness release
BDAR	=	battle damage assessment and repair
Bph	=	british thermal units per hour
CBTDEV	=	combat developer
CE	=	continuous evaluation
CFR	=	contractor flight release
CG	=	center of gravity
COIC	=	critical operational issues and criteria
CSC	=	computer software component
CSCI	=	computer software configuration item
CSU	=	computer software unit
cw	=	continuous wave
D	=	displacement, measured in units of length
DA	=	department of the army
DIDS	=	data item descriptions
DoD	=	department of defense
DOD-STD	=	department of defense standard
DOF	=	degree of freedom
DPRO	=	defense plant representative office
DT	=	developmental test
DT&E	=	developmental test and evaluation
ECCM	=	electronic counter-countermeasures
ECM	=	electronic countermeasures
EMCON	=	emission control
EMP	=	electromagnetic pulse
EMRH	=	electromagnetic radiation hazard
EMV	=	electromagnetic vulnerability
EOA	=	early operational assessment
EW	=	electronic warfare
F	=	force, measured in pounds
^{o}F	=	degrees, measured on Fahrenheit scale
FCA	=	functional configuration audit
FLIR	=	forward-looking infrared

FM	=	frequency modulation
FOE	=	follow-on evaluation
FOT	=	follow-on test
FOT&E	=	follow-on test and evaluation
FSD	=	full scale development
FSE		flight simulator evaluation
g	=	normal acceleration
HERO	=	hazards of electromagnetic radiation to ordnance
HWCI	=	hardware configuration item
I&T	=	integration and test
IGE	=	in-ground effect
IMC	=	instrument meteorological conditions
IOT	=	initial operational test
IPT	=	integrated product team
IR	=	infrared
IV&V	=	independent verification and validation
KIAS	=	knots indicated airspeed
LCSEC	=	life cycle software engineering center
LCSS	=	life cycle software support
LFT	=	live fire test
LRIP	=	low rate initial production
LTF	=	lead-the-fleet
MAA	=	mission area analysis
MATDEV	=	materiel developer
MDS	=	model, design, and series
MEP	=	mission equipment package
MER	=	memorandum of effort report
MET	=	mission task element
MJWG	=	manprint joint working group
MIL-STD	=	military standard
NBC	=	nuclear, biological, and chemical
OAT	=	outside air temperature
OEI	=	one engine inoperative
OFE	=	operational flight envelope
OGE	=	out-of-ground effect
OIPT	=	overarching integrated product team
OT		operational test
OT&E	=	operational test and evaluation
PA	=	procuring activity
PAE	=	preliminary army evaluation
PCM	=	pulse code modulation
PDSS	=	post-deployment software support
RAM	=	reliability, availability, and maintainability
REV	=	revolution
RF	=	radio frequency

RPM	=	revolution per minute
QSTAG	=	quadripartite standardization agreement
SAM	=	surface-to-air missile
SAS	=	stability augmentation system
SCR	=	system software change requests
SDC	=	sample data collection
SDF	=	software development folder
SEMI	=	special electromagnetic interference
SFE	=	service flight envelope
SLAD	=	survivability/lethality analysis directorate
SOW	=	statement of work
SRS	=	software requirements specification
STAR/STA	=	system threat assessment report/system threat assessment
STD	=	software test descriptions
STP	=	software test plan
STR	=	software test report
T&E	=	test and evaluation
TAD	=	target acquisition designation
TECOM	=	test and evaluation command
TEMP	=	test and evaluation master plan
TFE	=	technology flight evaluation
TIWG	=	test integration working group
TREE	=	transient radiation effects on electronics
USAF	=	united states air force
VMC	=	visual meteorological conditions
V/STOL	=	vertical/short takeoff and landing
VTOL	=	vertical take-off and landing
WIPT	=	working level integrated product teams